



IMPERIAL BUREAU OF FRUIT PRODUCTION

TECHNICAL COMMUNICATION No. 8

HORTICULTURAL ASPECTS OF WOOLLY APHIS CONTROL TOGETHER WITH A SURVEY OF THE LITERATURE

By

R. M. GREENSLADE, B.Sc., A.R.C.S.

East Malling Research Station

October, 1936

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FOREWORD

By MR. R. G. HATTON, C.B.E., M.A., V.M.H.,

Director of the East Malling Research Station and of the Imperial Bureau of Fruit Production, East Malling, Kent, England.

A memorandum and enquiry on horticultural aspects of woolly aphid control was circulated at the instigation of this Bureau to a wide circle of horticultural investigators and others in November, 1933. Since this memorandum shows exactly what was in the mind of the Bureau when it first contemplated issuing the present TECHNICAL COMMUNICATION, it is reproduced here as an appendix together with the names of those who so helpfully responded to the enquiries.

In view of the fact that Mr. Greenslade had been specializing at East Malling for years in the work of testing new seedlings for immunity to woolly aphid, of investigating control measures in the orchard, and of pursuing more fundamental studies into the possible causes of this immunity, the Bureau invited him to be responsible for the compilation of this resumé of the present position. He has had to undertake this work largely in his spare time, and he is certainly to be congratulated on the way in which he has selected the salient facts from amongst the mass of somewhat contradictory and inconclusive evidence and given a clear and concise account of the present position to the horticultural investigator.

In visiting the apple-growing areas of the Commonwealth I came to realize how vitally the attempts to control woolly aphid had affected horticultural practice in the selection of trees. Throughout Australia, New Zealand, and South Africa, with a few outstanding exceptions, the use of immune Northern Spy rootstocks (of which more than one type seems to exist) had become the general rule, not because it transmitted immunity to the scion, but because it afforded no harbour to a "root form" or "stage" of the pest. Whilst on many soils and with many varieties Northern Spy rootstocks produced first-rate orchards, it was quite obvious that, where certain limiting factors prevailed and with certain other scion varieties, unthrifty trees were the result. In addition, a considerable mass of correspondence has accumulated at East Malling which confirms this impression and voices a very general desire on the part of many horticulturists to return to the use of a more vigorous or "free" stock—of which only non-immune seedlings are generally known to them. There is ample evidence to prove that under similar conditions of environment it is possible to produce trees of much greater vigour than on Spy by the use of other but non-immune roots. This can be seen in the Huon Valley of Tasmania, in the Nelson district of New Zealand, and in the High Veld apple orchards near Vereeniging, South Africa, and in many other places. It has even been demonstrated that unthrifty trees on Spy can be reinvigorated by inarching vigorous rootstocks into their stems. However, despite the claims advanced for the complete efficiency of biological control of the pest by *Aphelinus mali*, there is still a very real reluctance to discard the much abused immune "Spy" for the non-immune seedling or even layered vigorous rootstock.

The obvious method of emerging from this horticultural impasse is the breeding and selection of a wider range of immune rootstocks or even of scion varieties. Mr. Greenslade

describes how far East Malling, with the advice and collaboration of the John Innes Horticultural Institution, developed this project under the auspices of the late Empire Marketing Board. However, before this very arduous task can be pushed further, the whole position calls for careful review, and Mr. Greenslade has put before the pomologist and plant breeder the evidence upon which they must decide their future policy with regard to woolly aphis control.

The Bureau very much hopes that the present communication may provoke a general expression of opinion from all quarters as to the best lines for the further development of this work which obviously calls for common and concerted action. The demand for a range of immune rootstocks is persistent and widespread from India and Kenya to South Africa and South America, but, in view of the present knowledge of the life history of the woolly aphis in relation to the roots, why is there not at least an equal demand for the introduction of immune scion varieties, especially in those areas where biological control is only effective in certain seasons? Where *Aphelinus mali* is effective, why is there still reluctance to solve the horticultural problem by testing out suitable non-immune rootstocks? This TECHNICAL COMMUNICATION will have attained its object, if such issues as these are carefully threshed out.

Finally, the Bureau wishes to thank Sir Guy Marshall and Dr. W. R. Thompson for their encouragement and interest in this effort of the Imperial Bureau of Fruit Production.

R.G.H.

July, 1936.

I. INTRODUCTORY

In the last hundred years there has been an ever-increasing amount of literature on the woolly aphid or American blight of apple trees (*Eriosoma lanigerum* (Hausm.)). Much of this is not easily accessible to horticultural officers and growers who are interested in the pest, and much of it seems at first sight contradictory. There appears to be disagreement for instance as to the amount of damage done to the tree, as to whether the aphid lives on the roots, and as to whether it migrates between apple and elm. There have been comprehensive accounts of the insect from the entomological aspect, but the facts in which horticulturists are mainly interested have not yet been collected together in a single publication.

This paper has therefore been prepared for the Imperial Bureau of Fruit Production as a guide to the published literature on the subject. The object has been to discuss the chief points of interest from the horticultural point of view, giving references to the literature, whence further details may be obtained when needed.

In order to make the information more complete, and to review the present position with regard to its control, the Imperial Bureau of Fruit Production sent out a questionnaire on the horticultural aspects of woolly aphid, the answers to which have been invaluable in assessing the present situation. Throughout the paper the authority for statement is given as the author's name and a date, e.g. (Marchal 1929), (Alden 12/1/34). The first of these is a reference to the bibliography at the end of the paper and the second indicates information from a reply to the questionnaire.

The writer is indebted to Mr. R. G. Hatton, Dr. A. M. Masee, and Mr. D. Akenhead for advice and criticism of this paper during its preparation, and also to those who supplied information on particular aspects of the question, Mr. F. Laing of the British Museum, the staff of the International Institute of Agriculture, Rome, and members of the staff of East Malling Research Station. He is also particularly indebted to Sir Guy Marshall and the staff of the Imperial Institute of Entomology for their valuable and much appreciated criticism of the manuscript. Thanks are especially due to all those who replied to the enquiry sent out by the Imperial Bureau of Fruit Production, a list of whom is to be found at the end of this paper. While all the information received was of great value in the preparation of this survey, particular mention may perhaps be made of the detailed accounts prepared by workers in all parts of Canada and the United States.

II. THE INSECT AND ITS HABITS

1. Origin.

It is generally agreed that *E. lanigerum* originated in the eastern half of North America. This view is supported by the fact that the aphid occurs there on American elm (*Ulmus americana*), which has been shown to be its primary host plant (Patch 1912), and by the existence of a parasite, *Aphelinus mali* (Haldeman), which is practically confined to woolly aphid on which it is an effective check. According to Banks (1818) it was first introduced to England about 1787, when it appeared in London in a nursery in Sloane Street. Banks thought that it was imported on apple trees from

France, but on enquiry he found it was unknown in France, and concluded it came from America (Kirby and Spence 1843). Since that time it has been distributed on nursery material to almost every apple-growing country in the world.

2. Synonymy The apple woolly aphid (*Eriosoma lanigerum* (Hausmann)) was first described by Hausmann in 1802, and the synonymy now stands as follows:—

<i>Aphis lanigera</i>	Hausmann	1802
<i>Coccus mali</i>	Bingley	1803
<i>Eriosoma mali</i>	Leach	1818
<i>Eriosoma mali</i>	Samouelle	1819
<i>Myzoxylus mali</i>	Blot	1831
<i>Schizoneura lanigera</i>	Hartig	1841
<i>Pemphigus pyri</i>	Fitch	1856
<i>Eriosoma pyri</i>	Riley	1869
<i>Schizoneura ulmi</i>	Woodworth	1913

A. C. Baker (1915) discusses this synonymy and gives a copy of the original description.

3. Description The structure of the various forms and the distinguishing characters of the species of *Eriosoma* are given by Baker 1915, Davidson 1913, de Fluiter 1931, Hausmann 1802, Jancke 1930, Marchal 1924, 1928, Mordvilko 1908, 1924, Theobald 1929, but need not be fully discussed here, as *Eriosoma lanigerum* is the only woolly aphid so far known to cause damage to apple trees. Other woolly aphides affecting cultivated plants are *Eriosoma lanuginosum* alternating between elm and the roots of pear, and *E. ulmi* alternating between elm and roots of *Ribes*, but neither of these has apparently been recorded from apple.

4. Life Cycle In the eastern United States the woolly aphid has a life cycle alternating between elm (*Ulmus americana*), the primary host, and apple, mountain ash, and hawthorn, the secondary hosts. According to Patch (1912) and others, the winter egg, laid on elm bark, produces in the spring the stem-mother or fundatrix which attacks the expanding bud and causes it to form a "rosette" of leaves in place of the normal shoot. Inside the "rosette" the fundatrix produces living wingless young (2nd generation). The offspring of these are the winged spring migrants (3rd generation) which fly to the secondary hosts and give rise to wingless females (4th generation). Several generations of these occur during the summer, and in autumn two forms are produced, (a) wingless viviparous females, similar to the summer forms, which remain on apple all the winter, and (b) winged forms (fall migrants), which return to the elm and produce the sexual males and females. The sexual forms have no mouth parts and do not feed but moult several times without increasing in size, and on pairing produce the winter egg. Thus in America apple trees may become infested from two sources, the spring migrants which come from elm, and the reserve of aphides which has been present on the apple all the winter.

In all other parts of the world the absence of American elm has made the normal migration impossible, and the life cycle on apple alone has survived. The winged forms are produced in autumn as in America, and these produce the sexual forms, and the egg is laid but either does not hatch, or if it hatches the resulting fundatrix cannot establish itself, so that this production of winter eggs is a "blind alley," and plays no part in the spread of the species (de Fluiter 1931, Marchal 1928).

The June and July winged forms produce three kinds of offspring, the sexual forms, wingless females similar to the summer generations, and sometimes small numbers of an "intermediate" form with a very short rostrum (Schneider-Orelli and Leuzinger 1926). The September winged forms produce only sexual forms and are by far the most numerous of the two winged generations. The wingless females produced by the early winged forms can establish themselves on apple trees

(Schneider-Orelli and Leuzinger 1926), but are not sufficiently numerous to be of any economic importance.

Experimental attempts to transfer *E. lanigerum* from apple to elm or elm to apple have been uniformly unsuccessful except in the eastern United States. The work of Marchal (1928) and of de Fluiter (1931) is of interest in this respect. They both succeeded in obtaining fundatrices from the winter egg, but were unable to establish new colonies with them, either on *Ulmus campestris* or on *U. americana*. Marchal concludes that in the course of a hundred years without American elm the insect has lost the ability to live upon it. Fundatrices obtained from America, however, would not establish themselves, and this was attributed to the fact that the elm was at the wrong stage of growth or was possibly not pure *U. americana*. Becker (1918) showed that backwardness of growth in spring is correlated with susceptibility of *U. americana* to attack by *E. lanigerum*. On early flushing trees the shoots would have grown away too much to be galled by the time the insect began to feed.

Börner (1932), on the other hand, maintains that *E. lanigerum* is confined to apple in America as elsewhere, and that the species which migrates from elm to apple, mountain ash, and hawthorn is *Eriosoma crataegi* Oestl. This species is so close to *E. lanigerum* that, in the original description, Oestlund (1887) considered it might prove to be *E. lanigerum*.

The records of Theobald (1921) and Monzen (1926) of migration from apple to *Ulmus campestris* are considered by Marchal (1928) to be due to faulty identification of the aphids.

The theories of Marchal and of Börner need further experimental and systematic work before either of them can be accepted as conclusive, but the views of Theobald and probably of Monzen cannot be accepted. There is enough evidence to show that in Europe at least there is no migration between apple and elm and that the whole life cycle is carried out on apple. Further information on alternation between apple and elm is to be found in other papers besides those already mentioned.*

5. Habit in Europe

Woolly aphid spends the winter on the trunk and branches, in wounds and cankers, under rough bark, and round the union of stock and scion when there is an overhanging bulge on the trunk. All stages are present at the beginning of winter, but the older insects die and by spring only the younger stages are present, (de Fluiter 1931, Greenslade 1935). Very little "wool" is secreted at this time, so that colonies are not conspicuous. This overwintering appears not to be a true hibernation, but merely a reduction of activity due to the low temperature. Marchal (1928) and Mordvilko (1923) describe an overwintering form, darker in colour than the normal and with five-segmented antennae instead of the normal six, but Jancke (1933) regards these characters as due to temperature and food conditions, and says they may appear in the summer, and that these insects are not a specially adapted overwintering form.

Activity in spring begins in March or April, according to the season, at which time the familiar "wool" is first noticed. The overwintered insects are adult and beginning to breed towards the end of May or in June. In July winged aphides appear among the much more numerous wingless forms, and these in turn give rise to further wingless forms (Schneider-Orelli and Leuzinger 1926). During August

* Baker 1915, Becker 1918, Gillette 1912, 1917, Gillette and Bragg 1915, del Guercio 1917, Hori 1930, Kalandadze 1930, Marchal 1919, 1924, 1933, Mordvilko 1923, 1924, 1929, Nevski 1925, Nicholls 1929, Patch 1913, 1916, Schneider-Orelli 1913, Schneider-Orelli and Leuzinger 1926, Venables 1929, Schoene and Underhill 1935.

there is often a temporary reduction in numbers of woolly aphid, sometimes amounting almost to a complete disappearance—it is not known where they go—followed by an increase in September (Jancke 1930). In September there is another appearance of winged aphides, which produce the sexual forms as already described (Schneider-Orelli 1918). Activity dies away during October and after leaf-fall very little aphid is to be seen.

6. Dispersal in the orchard

The species is spread in the orchard chiefly by means of the young wingless females in the first stage of development, which fall or are blown off the tree and walk to the next tree. They are also blown from tree to tree in the loose masses of "wool" (de Fluiter 1931, Greenslade 1935). Detailed studies of the movements of these young nymphs are given by Schoene and Underhill (1935). In addition to this, the winged insects and their wingless offspring which occur in July help to spread the species (Jancke 1930), but they are probably not numerous enough to be of economic importance. The young nymphs establish themselves on young new growth and water shoots, generally in the axil of a leaf where the bark is thin, and they can penetrate to the feeding layer. The galled areas produced by previous aphid attack and pruning or other wounds are also suitable for the establishment of young aphides. The dispersal of these young nymphs is at its height in July, and at this time there are large numbers to be found on the trunks of the trees. It is this dispersal which has so often been referred to as a migration to the roots.

7. Root infestation

In most parts of the world woolly aphid has been found living below ground on apple trees. This has always been referred to as root infestation, but examination of published records together with information obtained in an enquiry made by the Imperial Bureau of Fruit Production indicates that in most cases the aphid is in the top few inches of soil at the base of the trunk and suckers, and that serious infestation of the true root system is confined to certain areas, notably the south-eastern states of the U.S.A., South Africa, and Australia. This distribution of root infestation suggests that a comparatively dry and well aerated soil is necessary for *E. lanigerum*. In California, Essig (18/1/34) reports that root infestation is not severe in irrigated orchards, although un-irrigated orchards in the same district are badly affected. That the quality of the soil is not the most important factor is indicated by this, and by the existence of *E. ulmi* on roots of *Ribes* in areas where root infestation by *E. lanigerum* is not known. The quality of the soil is important within the areas of suitable climate. Both light and heavy soils have been stated to be more favourable to woolly aphid, but recently Marcovitch (1934) has obtained experimental evidence which supplements the observations of various workers, that clay soils are most conducive to root infestation. This is due to the cracking of the soil in dry weather which allows the aphides to reach the roots and to move about on them. Marcovitch (1934) also notes that soil temperature may for short periods rise high enough to kill woolly aphid. There is no evidence to show that the insects found on the roots, the so-called "root form," are in any way different from those on the upper parts of the tree. Neither is there any indication whether the insects can stay indefinitely below ground or whether they need to come up at any time during the life cycle. [The damage caused by root infestation is discussed later.]

8. Method of feeding and damage done

Woolly aphid at all stages of its growth feeds by means of its piercing and sucking mouth-parts on the bark of the tree. The leaves and fruit are not touched, though there are some records of feeding in the core of the fruit. The food is obtained from the layer of cells just outside the cambium (Staniland 1924) or at the cambium (Venables 1929, Heriot 1934), and the stimulation of the cambium results in the production of a swollen gall-like area which eventually cracks and provides a point of entry for canker fungi besides sheltering more aphides.

Growers of apples may suffer economic loss by several types of damage.

(a) Direct damage. This is important in seedlings, or young trees in which the young growing shoots may be killed or deformed, but in older trees it is not usually serious, unless the fruit spurs are attacked over a period of years.

(b) Indirect damage by providing a point of entry for various diseases. *Nectria galigena* (Wiltshire 1914, 1919) and *Gloeosporium perennans* (Childs 1929, Yothers 1933) are both wound parasites which may enter the tree through burst woolly aphid cankers, though not through feeding punctures. On the Pacific coast of North America *G. perennans* is one of the most serious problems, and woolly aphid is of importance mainly because it spreads the disease (Childs 1929) or helps in the spread of the disease. The insect has also been proved to carry fireblight (*Bacillus amylovorus*) on the outside of its body, but in this case it is not the most important transmitting agent (Gossard and Walton 1922, Merrill 1927). A species of *Cladosporium* has also been recorded as transmitted by woolly aphid (Dangeard 1892).

(c) Indirect damage by aggravating injury due to other causes. Winter injury of the bark due to alternate freezing and thawing causes an area of dead bark, and the edges of this dead area are colonised by woolly aphid, which forms cankers and prevents the wound healing. The cankering renders the bark still more susceptible to winter injury, so that the damaged area grows instead of healing. This type of damage is particularly serious in British Columbia (Buckell 8/2/34) and the north-western states of the U.S.A.

A curious case of this type of damage is noted by Gloyer and Fulton (1916). They noted the entry of a fungus *Leptosphaeria coniothyrium* at the punctures made by a tree cricket on laying its eggs. A canker formed and woolly aphid, taking shelter in the canker, stimulated it to further growth.

(d) Indirect damage in the nursery by loss of material not seriously damaged but rendered unsaleable by reason of the galls.

Damage to the roots. Damage to the root system leads to the death of the smaller infested roots and so lessens the supply of nourishment to the plants, but it is difficult to say whether the damage is ever sufficient to bring about this condition on established trees. There are records of trees with heavy root infestation continuing to crop for years and showing no loss of vigour. It is possible that root infestation on old trees is to be regarded more seriously as a source of reinfestation for the top than as a direct cause of damage. Sherbakoff and McClintock (1935) have shown that direct damage to the roots of young trees can be serious. On nursery stock the infestation of the roots may well cause serious loss. In the nursery also considerable damage may be done by aphides in stool beds on the bases of the stocks. They are buried as the stocks are earthed up and remain active below ground though not actually on the roots (Greenslade 1935).

9. Other host plants of *E. lanigerum*

The chief hosts of woolly aphid are apple and American elm. It has also been recorded from the following plants :—

<i>Crataegus Crus-galli</i>	<i>Cotoneaster horizontalis</i>
<i>C. punctata</i>	<i>C. acutifolia</i>
<i>C. Oxyacantha</i>	<i>Pyrus (Malus) Scheideckeri</i>
<i>C. cuneata</i>	<i>P. Aucuparia</i>
<i>Pyrus Toringo</i> (<i>P. (Malus) Sieboldii</i>)	<i>Cydonia vulgaris</i> (<i>Pyrus Cydonia</i>)
<i>P. (Sorbus) americana</i>	<i>Pyrus communis</i>
<i>P. americana</i> var. <i>decora</i>	<i>Salix</i> sp.
(<i>P. Sitchensis</i>)	<i>Syringa vulgaris</i>
<i>P. Malus</i> var. <i>Paradisiaca</i> (<i>P. Malus</i> var. <i>pumila</i> or <i>P. pumila paradisiaca</i>)	

According to Patch, *Pyrus americana*, *P. Sitchensis* and species of *Crataegus* are normal summer hosts in America. The rest are only occasionally infected. Some of these records may be due to faulty identification of the aphid. All are summer hosts and infestation of them in Europe is too rare to be of any economic importance as a source of infestation of apples.

III. EFFECT OF CLIMATE

Very little work has been done on the reaction of woolly aphid to the different individual climatic factors and the records of its climatic preferences are at first sight somewhat contradictory.

1. Temperature Records of the fatal limits of temperature are few. According to Marchal (1929), Keller in 1885 stated that individual aphides would withstand temperatures of -10° or -15°C . for short periods. Marcovitch (1934) found that 20°C . seemed to be the optimum temperature for development, and that 30°C . was unfavourable.

He also found that soil temperatures may become fatal in the summer. Schoene and Underhill (1935) studied the reaction to temperature of the young first-stage nymphs. In the open Mordvilko (1923, 1924) gives the northern limit of woolly aphid as the January isotherm of -3°C . in the Old World and -5°C . to -7°C . in America, the difference being due to the existence in America of a winter egg capable of standing a lower temperature than the active stages of the insect. Records of the disappearance of woolly aphid in late summer are frequent and this appears to be due to excessive heat. Marchal (1929) says that it is due to a reduction of the rate of reproduction rather than to the death of the aphid from the effects of heat. In countries in which root infestation is possible there may be a migration to the roots for shelter from the heat and dryness, but this has not been proved. It is also probable that this disappearance of woolly aphid is helped by the number of predators which are about at that time. The presence of a severe attack of woolly aphid leads to an increasing number of predacious coccinellids, syrphids, and neuropterous insects, and the decrease in numbers of woolly aphid due to heat leaves only a small food supply which is soon eaten up. The warmth or coldness of the climate may have several indirect effects on the degree of infestation by woolly aphid. Warm winters make for earlier growth of the aphid in spring and consequently more damage to the tree, and in very warm climates there may be no cessation of breeding and activity during the winter. Here also there may be no true dormant period for the tree, making it impossible to use tar-distillate winter washes which are among the best controls for woolly aphid. [See section on control of woolly aphid.]

In countries with cold wet winters the woolly aphid is reduced in numbers, and the introduced parasite, *Aphelinus mali*, which emerges early dies out again from lack of food supply, making it impossible to rely on natural control by the parasite. [See also biological control.] Very severe winters may lead to frost damage to the tree. [See method of feeding and damage done (c).]

2. Humidity and rainfall Marcovitch (1934) showed that at a temperature of 100°F . (37.7°C .) a relative humidity of 80 per cent was more favourable than either 100 per cent or 40 per cent, but the range of humidity at more normal temperatures has not been worked out.

In most European countries dry and hot seasons are favourable to development of woolly aphid, yet in some places it is said to breed best in damp seasons (Vereshceaghlin 1930, Uvarov 1919). This may be due to the normal rainfall in these places being below that necessary for proper growth of the tree.

In rainy seasons the dampness of the surface soil may hinder migration from tree to tree and this may also be partly the cause of the reported lack of infestation

in irrigated orchards in otherwise badly-affected areas (Essig 18/1/34). Hail is another factor which may increase the amount of damage when it is severe enough to cut the bark and make wounds which can be colonised by woolly aphids (Griffith 4/12/33).

3. Wind

The young first-stage nymphs of woolly aphids are carried from tree to tree by wind in the masses of "wool," and when they fall from the tree they must be carried a short distance before reaching the ground. Schoene and Underhill (1935) have evidence that their direction of movement is influenced by the wind even after they reach the ground. The same authors also show that the winged migrants tend to go with the prevailing wind, but that in a high wind they cling to the plant and will not fly.

4. Sunlight

Marcovitch (1924) showed that the length of daily exposure to light influenced the production of winged forms which bear the sexes in aphids. Shorter days or shorter light exposure led to the production of sexual forms. This he considered was probably due to alteration of the sap of the plant. One plant infested with *E. lanigerum* was brought into the laboratory in February in the course of these experiments and winged forms were produced, which, on dissection, were found to contain the true sex forms usually produced in the autumn. Except for this instance, there is no published evidence of the effect of light on woolly aphids, but it seems probable that the degree of infestation is affected by the increased vigour of the trees in a sunny year.

It seems then that the conditions necessary for a heavy attack are a balance of temperature, atmospheric and soil moisture, sunlight and other factors which exist naturally in Australia, South Africa, and parts of the United States. In other countries the conditions may be so nearly fulfilled that a slight alteration of one factor is enough to cause a heavy attack. Thus in England an increase of temperature and sunlight leads to a bad woolly aphid attack, in Rumania and Southern Russia a slight increase in rainfall has the same effect (Vereshceaghin 1930, Uvarov 1919). In other places so many of the factors are unfulfilled that serious infestation is rare. Of course, other factors may intervene to prevent serious attack even when climatic conditions are suitable, as probably happens in parts of the United States, where the presence of the parasite *Aphelinus mali* is considered to be one of the main reasons for lack of very serious infestation.

IV. CONTROL

1. Artificial Control

There are many reasons why woolly aphid is not easily controlled by the usual routine control programmes. In the first place colonies of the aphid are protected by a tangled mass of wax threads, the well-known "wool," which are secreted by each individual from a series of glands on the back. This mass of threads, because of its fineness and its waxy nature, is not easily wetted and a spray must hit the colony with some force to penetrate the "wool" and touch the insects. Then the fact that woolly aphid is a sucking insect means that the spray must come into contact with every insect, and, being a stem-feeding insect, it is largely protected by the leaves in summer. As the insect passes the winter as a young nymph protected by its wool instead of as an easily wetted egg, it is not so easily controlled by winter washing. Also hibernation takes place in crevices in the bark and broken galls where no spray can reach. Insects which reproduce sexually may be so reduced by spraying or other methods that they are too scattered for more than a few pairs to find each other, but woolly aphid reproduces parthenogenetically and a single female can start a colony. This, with the high rate of reproduction, makes woolly aphid control particularly difficult.

(a) Spraying.

In spraying against woolly aphid there are two possible methods of improving on the usual results, either very complete spraying so as to hit every colony, or increasing the wetting power of the spray so as to penetrate the "wool." The first of these methods is obviously wasteful, but it has been suggested that plain water can be used in this way. In an experiment in Australia, four sprayings in the course of the summer kept the pest in check (Anon, 1915), and the method has been used with varying success in Germany. The necessity of hitting each colony would seem to make this method rather uncertain, except possibly for garden use.

The other alternative, to increase the wetting power of the spray, is more helpful. Woolly aphid is just as susceptible as any other aphid to contact insecticides such as nicotine, tar distillates, kerosene or petroleum, and control is simply a question of wetting power.

Nicotine. This is generally used against woolly aphid at a concentration of 8-10 ozs. in 100 gallons, or nicotine sulphate 1 : 800 to 1 : 1,000. The fact that this concentration gives so much better results than the normal 4 or 5 ozs. used for other aphides suggests that the nicotine is acting partly as an asphyxiant as well as by direct contact. In the writer's experience, in fact, it is common after spraying with nicotine to find that the outer layers of "wool" have been wetted, but the aphides underneath are dry but dead, whereas after a petroleum spray they are alive. More efficient wetting so that the nicotine could act entirely by contact would enable a weaker nicotine solution to be used and this has suggested adding a solvent for the wax. Alcohol has been recommended, but usually in such low concentrations that the wetting power cannot be much improved, and Schulz (1922) has shown that cold alcohol has no solvent action on the wax. Lefroy (1917) also suggested carbon tetrachloride for garden use, but anything capable of dissolving the wax would be likely to raise the cost of spraying too much for commercial use.

The wetters most widely used with nicotine are soft soap and petroleum or kerosene emulsions. Very few comparative tests of wetting substances for woolly aphid have been published.

Tar distillates. Where tar distillate washes are used it is recognised that they are effective against woolly aphid, and it is also recognised that a higher concentration is necessary than for other aphides. Börner, Speyer and Jancke (1932), Maag (1923), and Van Poeteren (1916) all consider 10 per cent is necessary. With normal spraying, even 10 per cent only kills about 70 per cent of the aphides present, and 20 per cent is necessary for a complete kill (Greenslade 1935). This, of course, is commercially impossible, even if no damage were done to the trees. There is no doubt that the routine use of tar distillates even at 5 per cent does a lot to keep woolly aphid in check.

Petroleum sprays. Where tar distillate winter washes cannot be used, woolly aphid is generally controlled by 4 per cent petroleum sprays in the delayed dormant period, and by 1 per cent summer oil sprays with or without the addition of nicotine in the summer. It would seem that the addition of nicotine gives better control, since it is so often recommended. Comparative tests have not been published. Summer oil sprays with nicotine have the advantage of replacing a codlin-spray in some spraying schedules and so save applying an extra one. There is no published information as to what type of oil is most suitable for use against woolly aphid.

Various other oils have been tried with some success in place of mineral oils. Staniland (1927) mentions a 2 per cent rape oil emulsion. Balachowsky (1931) found that ground-nut oil and inferior grade olive oil emulsified with soap at 1 per cent were satisfactory substitutes for mineral oils. Mally (1934) used raw linseed oil and seal oil. He found, incidentally, that this treatment gave a control of irregular foliation.

Kerosene emulsions. These were formerly recommended for woolly aphid control. Resin solutions and pine tar creosote have been recommended (Cory 1923, Reppert, Schoene and Underhill 1922, France: Rapports sommaires—1933), and also soft soap solutions (Schneider-Orelli 1915, Jegen 1921). Austin (1929) used pyrethrum with which he obtained 45 per cent kill in a small trial, but some of this would be accounted for by the soap used.

(b) Dusting.

Dusting is often practised against woolly aphid, but its value is doubtful unless applied by means of a hand duster. Seabrook (1933) says that 3 per cent nicotine dust blown into the colonies as soon as they appear is effective. Ruhmann (1926) recommends the same treatment with calcium cyanide dust. Morrill (1921) claims to eradicate woolly aphid on small trees by nicotine dust blown from 3–4 feet, but the other writers who mention it agree that it must be blown into each individual colony of aphid and that a general dust cloud is no use. Passerini (1924) showed that pyrethrum dusts are useless against woolly aphid.

The number of different sprays recommended from time to time is an indication of the difficulty of controlling woolly aphid. The chief difficulty appears to be that, whatever spray is used, the method of application does not ensure that every colony is wetted. In summer the leaves afford so much protection that efficient wetting is impossible, hence it seems that the most hopeful line of investigation is to improve the wetting power of dormant sprays.

(c) Painting.

The most effective method of controlling woolly aphid on a small scale is by painting the colonies with an insecticide. This method has been practised since the pest first appeared and innumerable painting mixtures have been devised, mostly unnecessarily complicated. The use of a stiff brush is always advised, and this alone kills most of the aphides, the "paint" merely killing those inaccessible to the brush. Methylated spirit, paraffin emulsion, oil emulsions, oils, resin products, and tar-distillates are all recommended by various advisory institutions. All are effective, but are not very lasting. Repeated applications may be made in gardens or on nursery material, if labour is cheap enough. The advantage of this type of hand painting is that solutions can be used which would be injurious to the foliage if used as a spray and at a concentration which could not be used in a dormant spray. Probably better control could be obtained by attention to the time of application. At present all times from the beginning of the attack till late summer are recommended by various workers. In the garden, painting is often ineffective because lack of correct pruning leaves colonies of overwintering aphid on a tangle of thin shoots which it is almost impossible to paint. In certain cases hand-painting on a large scale is commercially profitable, as in parts of British Columbia (Buckell, 8/2/34, Dennys 1933). Here the most serious trouble is winter injury to the bark by alternate thawing and freezing. This produces an area of dead bark under which woolly aphid shelters in a position which cannot be reached by sprays. The galled area made by the aphid is especially susceptible to winter damage, so the damaged areas grow in concentric rings and it is, therefore, essential that wounds should be protected from woolly aphid. Dennys (1933) found that a mineral oil emulsion containing nicotine was a suitable paint for the purpose. The nicotine is held in the paint for a long time and wounds are kept free from woolly aphid for a year, during which time they heal and so reduce winter injury.

Childs (1930) found that the addition of nicotine sulphate increased the efficiency of various types of tree paints used for protecting wounds. In this case galls made by woolly aphid on wound callus collapse in the winter and make an entry

for the perennial canker fungus, *Gloeosporium perennans*. It is interesting to note here that Banks (1818) and Mosley (1820) claimed to keep the wounds free for a year by painting with train oil.

In general, hand-painting is only effective in the garden, and then only if combined with correct pruning and in the absence of any source of re-infestation. Where a source of re-infestation does exist, it is possible to protect wounds and cankers by painting but complete control is not practicable, as re-infestation takes place on the young shoots.

(d) Trapping.

Large numbers of wandering young nymphs of woolly aphid are caught on grease bands, so that where these are used they must have some small value as a control measure, but over-wintering generally takes place on the upper parts of the tree, and, unless there is a definite migration upwards from the roots, grease banding against woolly aphid alone would not be practical (Le Pelley 1928). Yothers (1932) found cardboard bands treated with beta-naphthol for codlin moth control were also destructive to such woolly aphid as came in contact with them.

(e) Fumigation.

Malenotti (1929) and Gurney and Brereton (1926) have tried the use of hydrocyanic acid gas on apple trees in Italy and Australia. In Italy Malenotti found that the concentration of gas necessary to kill the aphid was injurious to the tree in summer and the erection of tents caused the fall of many apples. Gurney and Brereton found that fumigation was costly and temporary in its effect. In the nursery, on the other hand, fumigation is a practical method of ensuring that dormant stock is free from woolly aphid before it is sold. The concentration of gas necessary is uncertain. Theobald (1908) used 10 ozs. sodium cyanide per 1,000 cubic feet of fumigation chamber with success. Staniland and Walton (1930) on the other hand found this concentration unsatisfactory. The writer has found 4 ozs. per 1,000 cubic feet satisfactory in a warmed fumigation chamber. The concentration of the gas varies greatly in different parts of a commercial fumigation chamber crowded with rootstocks or other material, so that though a large amount of fumigating materials may be used, the concentration of gas round some of the insects may be about zero. In the absence of circulating fans to ensure even distribution of gas, the material must be loosely and carefully stacked in the chamber and sufficient sodium cyanide used to kill all the aphid in all parts of the chamber. This amount can only be found by experiment in each case. In a limited experiment it was found that two types of apple rootstocks in the dormant state would withstand at least 32 ozs. sodium cyanide per 1,000 cubic feet without injurious effect on their growth in the next season (Greenslade 1936). [For soil fumigation see special methods for control on roots.]

(f) Manuring.

Much has been written, especially in popular journals in Germany, on the subject of controlling woolly aphid by manuring. It has been thought that heavy manuring with potash would enable the tree to throw off the attack of aphid. Most of these accounts mention very small tests, often uncontrolled. In order to clear up this point Jancke (1933) made an experimental test in which he showed that potash manuring had no effect on aphid infestation.

(g) Tree injection.

Attempts have been made to control woolly aphid by means of substances introduced into the sap of the tree, either as a solid put into a hole in the trunk, or as a liquid which the tree is allowed to absorb. Dementiev (1914) injected barium

chloride and potassium arsenite to control woolly aphid. He claimed to cure an infestation by means of barium chloride solutions, presumably without damage to the tree, but in one experiment at least the control was obtained at the beginning of September, and it should be remembered that the aphid often disappears naturally about this time. Müller (1926) records similar success with nicotine, pyridin, and with aluminium sulphate. Thiem (1931) claims that Müller's results with nicotine were due to poisoning by nicotine vapour and not by internal action. The problem of *Phylloxera* control by injection is in many ways similar to that of woolly aphid control, and Thiem found that he could not kill or drive away *Phylloxera*, scale insects, or weevils from vines, even if the vines remained standing in nicotine solution for a long time without damage. Jancke (1931) tried injection of nicotine against *Phylloxera* on vines, and found that, although nicotine appeared in the leaves, it did not get into the galled areas on which the insects feed.

In considering this method of attempting to control woolly aphid, two facts should be borne in mind. It is possible that insects may be driven away, not by any repellent action of the injected liquid, but by slight damage to the tree which makes it unsuitable as a food for the insects. This damage may not appear serious at the time the insects leave but may develop later, so that in experimental work it is important that definite statements of control should not be based on work with cut shoots or with trees which are not kept under observation for some time after the aphides have disappeared. It may also not be possible to inject a liquid so that it reaches the particular layer of cells from which the insect feeds, as was the case with Jancke's *Phylloxera* work, or this may be possible with some liquids and not with others.

(h) Cultural practice.

It has never been suggested that cultural methods could control woolly aphid, but various practices have an undoubted effect on its prevalence.

The fact that an orchard is cultivated or left down to grass probably has some effect on the spread of the aphid, but what that effect is has never been shown. Amongst widely-spaced young trees grass or some under-crop might shelter the wandering young nymphs from heat and dryness, on the other hand it might impede their progress and so reduce the spread. Cultivation actually at the time of migration would obviously kill very large numbers.

Irrigation must also prevent migration to a large extent, and in areas of heavy soil would tend to prevent cracking and so reduce root infestation.

Pruning also keeps the number down by removing many of the over-wintering colonies in broken galls on the one-year-old wood, and by keeping the tree open to the wind and sun. Underhill (1925) was able to reduce very greatly the infestation of seedlings in the first season by keeping them in cold store for two to four weeks and planting out after the migration from American elm ceased.

(i) Special methods for control on roots.

Control of woolly aphid on the roots of the trees is difficult and rarely effective. Soil fumigation with carbon bisulphide, paradichlorobenzene, cyanides, and tobacco dust are the most usual methods.

Carbon bisulphide is generally applied with some type of "soil injector," and allowed to vaporise in the soil in the hope that the vapour will reach the insects. The vapour of carbon bisulphide is toxic to woolly aphid, but Leach (1920) found that, if used in amounts sufficient to kill the aphid, it will damage the roots. The damage varies with the stage of growth of the tree, and appears to be due to interference with

the normal transpiration. Marcovitch (1934) says that an emulsion of miscible CS₂ in water at the rate of $\frac{1}{2}$ — $1\frac{1}{2}$ U.S. pints per tree (according to concentration) will control aphids on roots, but the cost is high.

Paradichlorobenzene is used successfully in some places, and is applied in a shallow trench and covered with soil. At Long Ashton Research Station (1927) it gave good results. In California it is also used successfully (Essig 18/1/34), but in other parts of the United States it has caused some damage to the roots (Rohwer 9/2/34). This again probably depends on the stage of growth of the tree and on soil conditions.

Cyanides. Sodium and calcium cyanide dusts are also used for control of "root form" of the aphid. Reppert, Schoene, and Underhill (1922) say that it causes damage to the roots.

Kerosene emulsion has also been recommended, but Leach (1918) showed that when poured on the soil the emulsion is discharged, the soap remaining in the first inch of soil and the kerosene does not penetrate far, but if it does it causes damage.

Tobacco dust and also creosote oil in water have been used successfully.

(j) Special methods for control in nursery.

Most of the published work on control in the nursery deals with the removal of aphids from material before sale. This is perhaps the most important consideration in the nursery, as in most countries it is illegal to sell apple trees or stocks infested by woolly aphids. It is also important that nursery material should be kept free from it at all times, as nursery conditions are favourable for a rapid spread and also the galls produced by the aphids may render the material unsaleable and are often mistaken by the customer for crown gall.

Dormant material may be cleaned by thorough dipping or spraying with various contact insecticides at a suitable concentration. Staniland and Walton (1930) found that 10 per cent tar oil wash (an old type of tar oil) was effective either for dipping or spraying. Nicotine (8 ozs. per 100 gallons) and soft soap was not so effective, but would probably be so with a high enough concentration of soap. Apple rootstocks have been shown to withstand treatment with soft soap solution at 20 and 30 lbs. per 100 gallons, and with tar distillates at 10 per cent, without any injurious effect on subsequent growth, and even tar distillates at 25 per cent caused no permanent injury (Greenslade 1936). Oil or kerosene emulsions or nicotine in these emulsions are also used (Wallace 1929). Dipping has the advantage over spraying that it ensures thorough wetting, and, where the plants will stand it, a higher concentration can be used, since there is little waste. [For treatment of nursery stock by fumigation see section on fumigation.]

2. Natural or biological control

(a) Predacious insects and other animals.

Woolly aphid in its natural state is kept in check by various predacious insects, chiefly the larvae of the syrphid flies and coccinellid beetles and their larvae. These sometimes become so numerous as almost to exterminate the aphids, particularly if the number of aphides has been reduced by climatic conditions, as sometimes happens in late summer. In these cases they are of considerable value, but experience shows that they are uncertain in their appearance and they are less resistant to spraying treatments than the aphids. A successful experiment in controlling woolly aphids with predators is recorded by Breen (1906), who introduced the beetle *Leis conformis* from Tasmania into Western Australia. The following predators have been recorded from various countries:—

Diptera : Syrphidae.

<i>Pipiza radicum</i> Walsh and Riley	U.S.A., Coquillett 1904, Davidson 1916.
<i>P. modesta</i> Lw.	California, Davidson 1916.
<i>Syrphus balteatus</i> DeG.	France, Marchal 1929 ; England, Rosenberg 1934 ; Japan, Nakayama, Tanaka and Maruta 1928, Hori 1930.
<i>S. ribesii</i> L.	France, Marchal 1929.
<i>S. auricollis</i> Mg.	England, Rosenberg 1934.
<i>S. similis</i> Blanch	Chile, Porter 1922.
<i>S. pusillus</i> Frog.	Australia, Jarvis 1922.
<i>S. viridiceps</i> McQ.	Australia, Jarvis 1922.
<i>S. venablesi</i> Curran	British Columbia, Venable 1929.
<i>S. opinator</i> O.S.	British Columbia, Venable 1929.
<i>S. meadi</i> Jones	British Columbia, Venable 1929.

Diptera : Cecidomyiidae.

<i>Uncinulella eriosomiperda</i> del	
Guercio	Italy, del Guercio 1918.

Coleoptera : Coccinellidae.

<i>Hippodamia convergens</i> Guér.	Colorado, Gillette and Taylor 1908.
	California, Clausen 1916.
<i>Cycloneda sanguinea</i> L.	California, Clausen 1916.
<i>Chilocorus bipustulatus</i> L.	Italy, del Guercio 1925 ; France, Marchal 1929.
<i>C. similis</i> Rossi	Japan, Hori 1930.
<i>C. rubidus</i> Hope	Japan, Hori 1930.
<i>Adalia bipunctata</i> L.	Italy, del Guercio 1925 ; France, Marchal 1929 ; Germany, Speyer 1935.
<i>Exochomus quadripustulatus</i> L.	Italy, del Guercio 1925 ; France, Marchal 1929 ; Yugoslavia, Kovačević 1932 ; Germany, Schmidt 1928, Speyer 1935.
<i>E. nigromaculatus</i> Gze.	S. Africa, 1921.
<i>Coccinella septempunctata</i> L.	Japan, Hori 1920 ; Germany, Speyer 1935.
<i>C. 9-notata</i> Hbst.	U.S.A., Marlatt.
<i>C. transversalis</i> F.	Colorado, Gillette and Taylor 1908.
<i>C. transversoguttata</i> Fald.	Colorado, Gillette and Taylor 1908.
<i>C. monticola</i> Muls.	Colorado, Gillette and Taylor 1908.
<i>C. quinquepunctata</i> L.	Germany, Speyer 1935.
<i>Scymnus hilarus</i> Motsch.	Japan, Hori 1930.
<i>S. cervicalis</i> Muls.	Missouri, Stedman 1897.
<i>Oenopia cinctella</i> Muls.	South Africa, 1921.
<i>Cydonia lunata</i> F.	South Africa, 1921.
<i>Alesia</i> sp.	South Africa, 1921.
<i>Leis conformis</i> Boisd.	Australia, Froggat 1912.
<i>Rhizobius</i> sp.	Australia, Froggat 1912.
<i>Adonia variegata</i> Gze.	Germany, Speyer 1935.

Neuroptera.

<i>Chrysopa septempunctata</i> Wesm...	England, Withycombe 1924 ; France, Marchal 1929 ; Kalandadze, 1927.
<i>C. vulgaris</i> Schneider	France, Marchal 1929 ; Germany, Röber 1921.
<i>C. walkeri</i> McLach.	France, Marchal 1929.
<i>C. cognata</i> McLach.	Japan, Nakayama, Tanaka and Maruta 1928, Hori 1930.
<i>C. formosa</i> Br.	Kalandadze, 1927.
<i>C. prasina</i> var. <i>abdominalis</i> Burm.	Kalandadze, 1927.
<i>C. porterina</i> Navás	Chile, Porter 1918.
<i>C. perla</i> L.	Kovačević, 1932.

Hemiptera: Capsidae.

<i>Camptobrochis nitens</i> Reut. ..	U.S.A. (Maine), Patch 1912.
<i>C. nebulosus</i> Uhl.	U.S.A. (Colorado), Patch 1912.
<i>Deraeocoris nitenatus</i> Knight ..	U.S.A., Knight 1921.
<i>D. ruber</i> L.	France, Marchal 1929.
<i>Capsus capillaris</i> F.	France, Marchal 1929.

Acarina.

<i>Allothrombium fuliginosum</i> Herm.	France, Marchal 1929.
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Birds.

Hennemann (1922) records that tits (*Paridae*) feed on woolly aphids, but not sufficiently to be of any use in control.

(b) Aphelinus mali and other parasites.

Aphelinus mali (Haldeman) is a member of the hymenopterous family *Eulophidae*, and occurs naturally on the eastern side of the United States and Canada, where it is one of the most important agents keeping woolly aphids in check. It is the only internal parasite which attacks woolly aphids in any numbers. It was first described by Haldeman in 1847, and the first scientific description was Haldeman's account in 1859. He described it as *Eriophilus mali*, and Howard in 1881 redescribed it, showing that *Eriophilus* was a synonym for *Aphelinus*. Synonyms of *A. mali* are *Blastothrix rosae* Ashmead, *Aphelinus varicornis* Girault.

The biology of *A. mali* has been studied by Lundie (1924) and Marchal (1929), and an outline only need be given here. The egg is laid in the body of the aphid, and hatches in three or four days, the larva lying free in the body cavity, not attached to any particular part. Lundie found that up to 140 eggs could be laid by a single female, and often more than one in each aphid. Only one larva, however, could develop in each host. Eggs are laid sometimes without previous fertilization of the female, but in this case the resulting progeny are all males. As the larva matures, the aphid dies and becomes hardened and blackened, and is fixed to the bark by a secretion from the body which seems to be stimulated by the parasite. The adult parasites emerge by biting a hole in the hardened body wall of the host. The total life cycle from egg to adult varies according to the temperature, but there is also considerable variation in the time for different individuals under apparently similar conditions. In Lundie's experience it was generally from 20 to 29 days with six generations in the year and a partial seventh. Up to twelve generations have been recorded (Meier and Telenga 1933), and the time of development is so variable that generations soon overlap. Hibernation occurs as a full-grown larva in the body of the host.

The use of *Aphelinus mali* as a control for woolly aphid was first attempted by P. Marchal and L. O. Howard in 1918, when material was sent from America to France. It was not till 1920, however, that a successful establishment in France was made, when parasitised aphides were brought over in cold store. Since the establishment of *Aphelinus* in France it has been introduced into almost every country where woolly aphid is serious. Accounts of the use of *Aphelinus* in various countries have been made by Marchal up to 1929, by Sprengel to 1930.

The parasites are generally established in a new area by placing in the orchard twigs covered with parasitised aphides in wire gauze cages. The mesh of the gauze is such that the parasites can escape, but predacious insects cannot get in. For transport over long distances they can be kept in cold store. Ripper (1932) recommends using the adults, which can be kept alive for some time if fed on sugar, and released in suitable weather. This method also avoids distributing canker which may be present in the twigs. *Aphelinus mali* has special advantages as a parasite. It is fairly free from hyperparasites. *Pachyneuron* sp., *Asaphes americana* (Lundie 1924) in America, and *Pachyneuron aphidis* Bch., *Asaphes vulgaris* Wlk. in Russia and Germany (Meier and Telenga 1933, Sprengel 1931) are the only hyperparasites recorded and these only in small numbers. *A. mali* is practically confined to one host, *Eriosoma lanigerum*. It has been recorded from a number of other hosts, but many of these records may be due to faulty identification of the parasite (Marchal 1929), since there are many very similar species of *Aphelinus*. It has been bred experimentally on a few other aphides, but the preference for *E. lanigerum* is very strong, so that the parasite can be relied upon to attack only *E. lanigerum*. The preference is, in fact, so strong that, when *E. lanigerum* is exterminated, the parasite dies out instead of attacking another species of aphid, so that it cannot be used, where woolly aphid is scattered or sporadic in its appearance. The following aphides have been recorded as alternative hosts of *Aphelinus mali*, or have been tried experimentally as alternative hosts:—

Host.	Recorded by—
<i>Eriosoma americanum</i> (Riley).	
<i>Eriosoma crataegi</i> (Oestl.)	Girault 1909.
<i>Eriosoma patchiae</i> (B. and B.) (= <i>E. ulmosedens</i> Marchal)	Marchal 1929.
<i>Eriosoma lanuginosum</i> (Hartig)	Malenotti 1923.
<i>Tetraneura colophoidea</i>	Howard 1908.
<i>Prociphilus fraxinifolii</i> (Riley)	Webster and Phillips 1912.
<i>Colopha ulmicola</i> (Fitch)	
<i>Aphis monardae</i> Oestl.	Webster 1909.
<i>Aphis sacchari</i> Zehnt.	
<i>Aphis mali</i> F. (? = <i>A. pomi</i> De G.)	
<i>Aphis tavaresi</i> Del G.	Newman 1924.
<i>Brevicoryne brassicae</i> (L.)	
<i>Hysteronura setariae</i> (Thos.).	
<i>Toxoptera graminum</i> Rond.	Webster 1909.
<i>Toxoptera aurantii</i> Boy.	Jarvis 1926.
<i>Macrosiphum rosae</i> (L.)	Ashmead 1886.
<i>Myzus mahaleb</i> (Koch)	Webster 1893.
<i>Macrosiphum</i> sp. on citrus	Newman 1926.
<i>Aphis nerii</i> Boy.	Newman 19/9/34.
<i>Macrosiphum</i> sp. on geranium	Gurney 11/7/34.
An aphid on <i>Panicum</i> .	

Lundie (1923), mentioning the record of *Brevicoryne brassicae* (L.) as a host for *A. mali*, says it is not a preferred host. Marchal (1929) could not induce *A. mali* to attack this species.

Girault (1909) described *Aphelinus varicornis* parasitic on *Eriosoma crataegi*, but this now appears to be identical with *A. mali*.

Howard in 1908 records *Tetraneura colophioidea* as a host for *A. mali*. It was reared from material collected by Pergande in 1897 from this aphid, but it seems that *T. colophioidea* was never described, and is probably a manuscript name of Pergande. Jarvis (1926) records the use of *A. mali* against the "black citrus aphid" which has been interpreted as *T. aurantii* Boy. Newman (1924) says that *A. mali* had been recorded from this host in New Zealand.

Some of these records are, no doubt, due to mistaken identification of the parasite concerned, but *Aphelinus mali* evidently does parasitise other species of aphides occasionally. In nature this probably does not occur to any extent, as the preference for *E. lanigerum* is very strong.

A. mali is not much affected by spraying against other pests. According to Gurney and Brereton (1926), arsenicals have no effect and contact insecticides very little. Tillyard (1923) says that the adults and pupae are not affected by sprays, but oil, soap, or tobacco washes will kill the larvae; Noble (1935), however, showed that this does not apply to mature larvae. Malenotti (1929) found that some of the parasites survived fumigation with hydrogen cyanide. Jancke (1935) mentions various proprietary sprays, and says that tar distillates kill so many of the parasites that, where they are used regularly, fresh colonies would have to be put out every spring. It is possible, however, that this loss may be counter-balanced to some extent by the destruction of many predators which do not discriminate between parasitised and unparasitised aphides, especially where the predators breed very rapidly. Very frequent spraying or dusting, as against *Thrips imaginis*, may kill many of the adult parasites (Noble 1935).

Experience in Europe. The usefulness of *Aphelinus mali* in Europe is restricted by climate. It can withstand extremes of dry cold as is evident from the observations of Menzel (1930), Werneck (1932), and Jancke (1929), but it does not like wet or fog. Romanova (1935) describes the use of *A. mali* in two localities in the Caucasus which differed in climate. In the dry area with a cold winter there were eight generations, and in the mild wet area six, with a period of activity three weeks shorter than in the dry area. In the wetter area the aphid was not plentiful until July, so that the parasite spread slowly. Development ceased at temperatures below 13°C., and the hibernating larvae entered a state of diapause below 8–10°C. Ripper (1931) says that the parasites are susceptible to rain and also, if the spring is mild, they emerge before the host is about in sufficient numbers, and so die out. The adults do not fly freely in wet weather, and probably wet also hampers their emergence. According to Meier and Telenga (1933), the adults are active on sunny days, but do not like direct sunlight. They are most numerous on the shady side of a tree, and do not fly far in the absence of wind.

Aphelinus mali has now been used up to fifteen years in various countries, and the evidence obtained as to its usefulness is probably conclusive. In Europe it is only partly successful, being most useful in Italy. There it generally controls the aphid, except in the more rainy northern provinces. Even in the south in some seasons damage may be done before the aphid is brought under control. In France it is likewise useful in the south, but too uncertain to be practical in the north. In England it has only been established in certain cases, generally emerging rather too early in the spring, and it does not overtake the aphid until late in the season when

all the damage is done. Also it ceases to be active in autumn before the aphid, so that the latter has time to increase and spread slightly before the winter. In Holland and Germany much the same conditions are found. The parasite can be established in some districts, but the late appearance of woolly aphid in spring limits the spread of the parasite. Jancke (1934) points out that the reduction in numbers of the host in late summer also reduces the number of the parasites.

Experience outside Europe. In the western side of Canada and the United States, where it has been successfully introduced, it assists in the control of woolly aphid, but does not as a rule exterminate the pest (Buckell 8/2/34, Childs 17/1/34). In South Africa it controls the aphid completely in some areas, and is useful in others (C. C. Cunningham 11/4/34, Griffith 4/12/33, Pickstone 2/3/34). The usefulness of *Aphelinus mali* seems to be greatest in Australia and New Zealand. In most districts, especially where immune rootstocks are used, the aphid is completely controlled, or so nearly controlled that other control methods are unnecessary. There are, of course, certain areas where it does not succeed for climatic or other reasons, but on the whole the climates of New Zealand and Australia suit the parasite.*

Aphelinus mali has been introduced into the following countries :—

Europe : Austria, Belgium, England, France, Germany, Holland, Hungary, Italy, Jugo-slavia, Poland, Portugal, Spain, Switzerland, U.S.S.R.

Africa : Algeria, Kenya, Morocco, Union of South Africa.

Australasia : New Zealand and Australia.

South America : Argentina, Brazil, Chile, Ecuador, Peru, Uruguay.

As regards other parasites, Gautier and Bonnamour (1931) describe *Aphidius palpator* sp. n. as being possibly parasitic on *E. lanigerum*.

Waterston (1926) describes *Praon lepelleyi* sp. n. as a parasite of *E. lanigerum*. This has only been recorded once, when Le Pelley bred it at East Malling. The types, however, are labelled "bred from *E. lanigerum* on elm," so that it is possible the aphid was not *E. lanigerum*, which would account for the parasite not being noted again.

(c) Other methods of biological control.

A popular idea of unknown origin is that *Tropaeolum* (nasturtiums) grown round an apple tree will prevent it being attacked by woolly aphid. Theobald (1910) records an experiment on three trees in which two trees had *Tropaeolum* planted round them and were cleared of woolly aphid, while the third remained infested. This was only done in one year, and it is most probable that the result was coincidence. In 1934 Fox-Wilson published an account of similar experiments, also on a small scale, but repeated many times on different varieties of apple, showing that there is no foundation for this old idea. Another account also confirms this (Cheeseman 1934). The statement that apple trees growing near walnuts are resistant to woolly aphid is probably equally mistaken (André 1904).

The control of woolly aphid by means of a parasitic fungus *Sporotrichum globuliferans* was tried by Paillot (1917) without success.

* Correspondence : G. H. Cunningham 13/2/34, Goodwin 17/5/34, Miller 9/5/34, Taylor 21/5/34, Triggs 21/4/35, Gurney 11/7/34, Hall 9/6/34, Nicholls 17/1/34, Newman 19/9/34, Quinn 26/11/34, L. A. Thomas and Veitch 21/3/34.

3. Control by (a) Resistant varieties already in use.

the use of
resistant
stocks or
varieties
of apple

It is well known that in practice many varieties of apple are not attacked to any extent by woolly aphid, while others suffer badly. The variety Northern Spy, grown for its fruit in eastern Canada and the United States and in parts of New Zealand, never suffers damage. Other varieties, notably Allington Pippin, may be heavily infested year after year, though the trees round about are free from the aphid. Many valuable susceptible varieties cannot yet be replaced by equally valuable resistant ones, but until this can be done the quality of resistance can be made use of in rootstocks. Where root infestation is prevalent the roots form a "reservoir" of aphid which cannot be controlled by ordinary means, but "immune" or "blight proof" rootstocks have been used successfully for this purpose for many years. The most widely used variety for this purpose is the Northern Spy, which has been used with considerable success in Australia and New Zealand, and to some extent in South Africa. As a rootstock Northern Spy is not altogether satisfactory, or rather, like other stocks, it is not successful in certain areas and with certain scions. The usual criticisms are that it is too shallow rooting and does not make big enough trees. In New Zealand, according to Woodhead (1933), trees of certain varieties on some deep, fertile soils lack vigour on Northern Spy stocks, though in other parts of New Zealand trees on Spy come into bearing early and produce highly coloured fruit of good quality. When the variety Sturmer Pippin has been worked on Northern Spy, the growth of new wood has been found to decrease very rapidly after fruiting has commenced (Allen and Woodhead 1933). Northern Spy cannot be raised easily by ordinary stooling methods, and it is necessary to use special methods (Woodhead 1934) or to bench graft Spy stem on Spy roots and bud a year later, or resort to layering. In some cases Spy does not make a very good maiden tree (Hatton 1928). Woodhead in the paper mentioned above (1933) showed that whereas Northern Spy stocks raised from layers were shallow rooting, those raised from root cuttings were deep rooting and much more vigorous. Allen and Woodhead (1933) have raised Northern Spy stocks from a collection of root cuttings from all over New Zealand, and graded them according to botanical characters. They have found nine distinct types, of which one may not be true Northern Spy, which vary in vigour. Results of the performance of these types as rootstocks are not yet available. The authors also suggest that stocks other than Spy may be necessary for certain varieties of weak growth.

As to the behaviour of this quality of immunity, Northern Spy is completely immune from damage by woolly aphid. This is not to say that woolly aphid is never found on Spy. Le Pelley (1927) showed that the aphid could exist on Northern Spy for a time but does not breed or form colonies, and does no damage to the plant. This also has been the experience of other workers. Resistance to woolly aphid is not transmitted by a resistant stock to a susceptible scion, as is known from commercial practice, nor by a resistant scion to a susceptible stock (Fluke 1930). Le Pelley and Crane have shown (Le Pelley 1927) that the resistance of Spy is inherited by some of the seedlings in a cross between Spy and a susceptible variety, so that it may be possible to breed stocks of good character having the quality of resistance. Work on this is in progress. Occasionally in the field Northern Spy is said not to be resistant. Quinn (26/11/34) says that where the plough cuts into the roots of Spy stocks the resulting stool growth sometimes bears woolly aphid colonies for a time. Drain (6/1/34) reports that Northern Spy is not fully immune in Tennessee. A seedling of Spy, "No. 227," has been raised at Washington D.C., which is just as resistant there as Spy itself, but Gardner and Yerkes (21/11/33) state that this has not proved resistant in Tennessee. In this connection it is interesting to note that there are records of varieties which are generally considered highly susceptible being resistant in particular areas. Jegen (1924) records Cox's Orange Pippin and

Blenheim Orange as resistant, whereas they are usually found to be susceptible. Cox has also been classed as resistant in India. The varieties Delicious and Fameuse are found to be resistant in Tasmania, but are said to be susceptible in New South Wales (P. H. Thomas 8/3/34). Delicious is also claimed to be resistant in the Middle West of the United States, but is not resistant in California (Essig 18/1/34). It has been suggested that resistance to woolly aphis is affected by the soil, particularly with varieties on the borderline of resistance, but there is no published evidence to support this.

Another variety to be used in numbers as a stock is Winter Majetin, which is completely resistant to woolly aphis and is found to be more useful than Spy in wet situations. Moreover, the resistant variety Ivory's Double Vigour was introduced into New Zealand to overcome the objection to the lack of vigour shown by trees on Northern Spy.

(b) Breeding for immunity.

The fact that some of the seedlings obtained by crossing Northern Spy with a susceptible variety will inherit the resistance of Spy naturally suggested that a range of new varieties could be produced having the quality of resistance, but being more suitable for general use than the existing resistant varieties. The production of new scion varieties by this method is slow, but practicable.

Breeding work is being carried out in England at Merton and East Malling, in the United States at Washington, and in Germany at Naumburg/Saale. An account of the work of the English stations is given by Crane, Greenslade, Massee, and Tydeman (1936). The objects of this work have been to obtain information on the genetical behaviour of the quality of "immunity" and to raise a series of rootstocks of similar behaviour to the East Malling types of "Paradise" rootstocks (Hatton 1917, 1919) but immune from attacks of woolly aphis. At first the "Paradise" varieties were crossed with Northern Spy only, but later other highly resistant varieties were included. The seedlings so raised are tested for immunity from woolly aphis by inoculation during two seasons with aphides, and those which remain immune after this treatment are tested for ease of propagation and behaviour as rootstocks. Up to date this work has produced 573 new varieties found, at East Malling, to be immune to aphis attack, but as yet untested in the nursery. In addition to these, four new, immune varieties have now been proved by tests in nursery and orchard to be suitable for use as rootstocks. These stocks, known at present as Merton 778, 779, 789, and 793, were all raised by crossing Northern Spy with the Malling No. II rootstock. The behaviour of these stocks in the nursery and orchard is described by Tydeman (1935, 1936) and by Crane, Greenslade, Massee, and Tydeman (1936). Small quantities of these immune stocks are being tested entomologically in various countries, and, although they are completely immune in England under the most vigorous tests, one has proved slightly susceptible in Canada. This suggests that, whatever may be the main cause of immunity, the problem is complicated by other factors which must be discovered before a complete solution is possible.

(c) Causes of resistance.

The first attempt to explain resistance to woolly aphis was made by French (1891), who gave the results of ash analyses of Winter Majetin and a susceptible crab. The Majetin material was found to contain more calcium. There is no experimental evidence to show that the differences found would account for resistance. Staniland (1924) examined the structure of the shoots of different varieties, and found that the amount of sclerenchyma in the stem showed some relation to degree of resistance but could not explain resistance amounting almost to immunity. It has been suggested that the acidity of the sap influences the resistance of vines to *Phylloxera*

and Monzen (1926), following this idea, made some experiments with apples, from which he concluded that the sap of varieties resistant to woolly aphid is more acid than that of susceptibles. Roach and Massee in 1931 published a preliminary account of work on the causes of immunity, in which they describe a method of feeding aphides on bark extracts in order to examine their behaviour when supplied with different chemical fractions of the bark. There was a suggestion that on certain extracts of the bark of a resistant variety the rate of reproduction was lower than on a similar extract prepared from a susceptible variety. A further progress report on this work (Greenslade, Massee, and Roach 1934) indicates that resistance is due to a chemical substance present either in the susceptible variety or in the "immune" variety and which is soluble in ether but insoluble in alcohol.

4. Legislation

Most countries have regulations as to the import and sale of insect-infested plants and the control of pests. Where apples are grown the pests specified or implied nearly always include *E. lanigerum*. The import regulations generally provide for examination of the plants by a Quarantine Service and certification of the plants by the authorities of the country of origin. In the Union of South Africa and in Southern Rhodesia there have been regulations prohibiting the import of apple stocks not accepted as resistant to woolly aphid. To prevent the spread and undue multiplication of pests within a country there are various orders restricting the sale and transport of infested plants and providing for inspection of orchards and nurseries. These orders may compel all owners of fruit trees to control pests, as is done in parts of Germany against woolly aphid, or compulsion may be used on a complaint from neighbouring growers as in England.

As an example of the use of legislation to assist in the control of pests, including woolly aphid, the regulations in force in England may be quoted. They consist of Orders made under the Destructive Insects and Pests Acts, 1877-1927.

Import of plants.

The Importation of Plants Order of 1933 requires that all plants imported into this country must have a certificate of examination by the authorities of the country in which they were grown, showing that they are free from any insect or other pest or disease destructive to agricultural or horticultural crops. Although *E. lanigerum* is not specified as in previous orders, this order would prevent its reintroduction, on foreign material, to districts from which it may at any time be exterminated.

Export of plants.

Most countries require a certificate from the Ministry of Agriculture before plants may be imported from this country. The presence of woolly aphid would, of course, prevent the award of this certificate.

Sale of plants.

The Sale of Diseased Plants Order of 1927 prohibits the sale of plants infested with a number of pests, among which is included woolly aphid.

Control and prevention of spread.

The Fruit Tree Pests Orders in force in certain counties are intended to prevent neglected orchards from becoming sources of infestation for other land. The schedule of pests includes all "fruit tree aphides." By these orders a grower who considers that his neighbour's trees are so infested that the pests are liable to spread to his own trees may complain to the local authority, the county or borough council, who will send an inspector to report on the case. If the complaint is found to be justified, a copy of the report is sent to the occupier, followed by a notice of intention to compel him to control the pest. After considering

any objections he may make, he is served with a notice requiring him to treat his trees by a specified method or to destroy them. Failure to comply with the order entails a fine of £10, or, for a second offence, £50.

V. ECONOMIC IMPORTANCE

The information obtained from the literature and from the replies to an enquiry sent out by the Imperial Bureau of Fruit Production shows that the pest is always serious in the nursery and under some conditions is also important in the orchard. Growers of apples in Australia, New Zealand, and South Africa have probably suffered the heaviest losses through woolly aphis. In these countries root infestation occurs, which makes control very difficult and expensive, even when no direct damage is done to the roots. The use of "blight proof" rootstocks together with the use of the parasite have improved the position in Australia and New Zealand, so that the aphis is not regarded so seriously at the present time. In South Africa, however, the use of the parasite has not progressed very far, and control on the upper parts of the tree is still a major consideration with the grower. In most parts of Canada and the United States no serious damage occurs, as either the climate is unsuitable or the parasite keeps it in check. The aphis is only important in British Columbia and the Pacific North Western States, where it is associated with winter injury and with perennial canker, and in Tennessee and the neighbouring States, where its ability to live on the roots causes some loss in the nursery. In Europe woolly aphis is of economic importance in the nursery, and serious damage in established orchards is less general in most seasons. It may be more serious on certain highly susceptible varieties or in certain seasons. In Italy it causes more damage than in most parts of Europe, but this has been considerably reduced by the use of *Aphelinus mali*.

Knowledge of woolly aphis problems is still somewhat incomplete. In the first place the actual amount of damage caused is not known. When the laterals all down the branches are seriously affected, and when seedlings or the growing points of young trees are killed or stunted, the damage is fairly obvious, but often it is not known how much loss of crop occurs on established trees, and especially it is not known how much damage is caused by root infestation. Neither is it known how cultural practices and the state of health of the tree affect the degree of attack. No satisfactory control measure has yet been evolved for use where the parasite cannot be used. Finally, the behaviour of the quality of resistance to the aphis is but little understood and the actual cause of that resistance is still unknown.

VI. SUMMARY

The published information on *E. lanigerum* is reviewed.

The aspects of the problem which are most interesting to horticulturists are fully discussed.

The insect and its habits in Europe and America are described, and an account is given of the damage done by it.

The effect of climate on the seriousness of its incidence is noted.

The control of the insect by spraying, by biological methods, and by the use of resistant varieties, is considered.

An annotated bibliography of 600 references is appended.

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In the accompanying bibliographies the titles are given in alphabetical order of the authors' names, but, as there are so many dealing with control by means of *Aphelinus mali*, a separate list has been made of these. Papers which contain information on other aspects, as well as on parasitic control, appear in both lists. As many references as possible have been included, but since many of them are popular advisory notes and not original work, a brief note has been added in most cases where the title is not self-explanatory. A reference to the *Review of Applied Entomology* appears under the titles of all papers abstracted by the Imperial Institute of Entomology, thus R.A.E., A.9: 174. Also, where possible, reference is made to the *Experiment Station Record*, thus E.S.R., 70 : 185.

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APPENDIX.

1. A MEMORANDUM AND QUESTIONNAIRE ON THE CONTROL OF WOOLLY APHIS (*ERIOSOMA LANIGERUM* HAUSM.)

Issued in November, 1933, by the Imperial Bureau of Fruit Production.

HORTICULTURAL ASPECTS OF WOOLLY APHIS CONTROL.

A MEMORANDUM AND ENQUIRY.

THE search for an efficient control of woolly aphis *Eriosoma lanigerum* Hausm. is nothing new. For many years much laborious research has been devoted to the problem both in Europe and throughout the apple growing districts of the world. The main lines on which the attack has been developed may be classified as follows :—

1. Field Control Measures.

Although some measure of control of the aerial form can be obtained by repeated and, therefore, costly sprayings or fumigations, below ground all methods either of spraying, fumigation, or soil injection have proved ineffective, nor is it desirable that the cost of such methods should be added to the already too heavy expenses which commercial orchards are called upon to bear.

2. Biologic Control.

It was at one time thought that a complete control might be obtained by means of the Chalcid parasite *Aphelinus mali* Hald. This parasite, a native of North America, was described by Haldeman¹ in 1859 and redescribed by Howard in 1881. It was introduced into France by Howard and Marchal² in 1920. In the following year it was brought into New Zealand by Tillyard and into Uruguay by Sundberg. These three centres have served for its further dissemination, and it has now been employed in most if not all countries to whom the destruction of the aphis is important. In countries where the climate has enabled it to breed freely the parasite has undoubtedly gained a considerable measure of success, yet in each country where the parasite has become definitely established there appears to be a limiting factor operating against the achievement of complete control. In South Africa for instance, where it breeds well, certain growers report that it frequently does not attain sufficient numbers to be dangerous to the aphis until too late in the season, when much damage has already been done. The fact, too, that the parasite cannot attack the aphis below ground may mean that at best it can never be more than a partial remedy.

3. Immune Varieties.

Published reports at one time or another have claimed some 300 varieties of apple to be either immune or highly resistant. There is, however, evidence to show that varieties on this list immune in some countries are not so in others. For example, varieties considered in India to be immune have become infested on introduction to England. Cox's Orange Pippin considered as immune by Jegen in Switzerland is one of England's most susceptible varieties, while recent experiments in Holland have shown that this variety can be easily infected there also. From these and other contradictory announcements it is clear that a certain amount of confusion exists. It would, indeed, be interesting to know the nature of the tests and observations on

¹ Haldeman, 1860. *Proc. Boston Soc. Nat. Hist.*, 6 : 402.

² Marchal, P., *Ann. Epiphyties*, 1929, 15^e année, pp. 125-181.

which many of these statements are based. Experience suggests that direct inoculations are necessary and that conclusions based on field observations alone are not sufficient.

4. Immune Rootstocks.

Immunity from underground attack has been obtained in New Zealand and Australia by the use of the Northern Spy rootstock, but there is ample evidence that Northern Spy often exhibits characters extremely undesirable in a stock. The variability of this variety is well shown by the recent work in New Zealand of Allan and Woodhead ("Apple Rootstock Investigations," *N. Zealand J. Agr.*, 1933, 46 : 256-9) which has already resulted in the segregation of Spy into nine types with the probability of more to follow.

In the early days of the rootstock work at East Malling the question of the immunity of the so-called Malling stocks was raised. The work of testing this was started by Staniland in 1921 and proved that none was immune. Since then collaboration between the John Innes Horticultural Institution, Merton, and the East Malling Research Station has aimed at the production of rootstocks which should be equally as resistant to the pest as Northern Spy or other immune varieties, but should possess considerably higher qualities as rootstocks than Northern Spy would appear generally to have. The plant breeder, the pomologist, the entomologist, and the chemist have all been involved in the work of crossing Spy and later other immune stocks and of testing out the resulting seedlings first for immunity and subsequently as stocks, both at East Malling and in other parts of the world. Incidentally, there is no reason why among the immune varieties of rootstock raised there should not be some good scion varieties.

5. Fundamental Research.

At East Malling, too, the determining factor in immunity is being sought, and biologist and chemist have already started along certain lines, in particular the chemical analysis of immunes and non-immunes, and the culture of aphid on artificial media.

It is evident that the investigations now proceeding in so many directions and in so many lands represent a great expenditure of work and energy. Is this effort producing its maximum effect without waste? Does it not seem that the time has come for a review of the position and for dovetailing the separate items of research into one coherent whole to the mutual advantage of workers in this field? In the belief that the time is ripe for clearing up many points still obscure, and for encouraging the closest co-operation among the workers concerned in such investigations as shall lead to an early solution of the problem, we are asking you to give us your help in collecting the scattered threads of information so that we may weave the entire story into a coherent whole and present it adequately documented as a Technical Communication.

We are aware that Marchal¹ in France, Mordvilko² in Russia, and de Fluiter³ in Holland have already produced their admirable monographs, but the communication we contemplate will deal with the subject from a pomological standpoint, a work which hitherto has not been attempted.

A questionnaire is enclosed which is not meant to be exclusive, but may, it is thought, act as a basis for your replies.

We have what we believe to be a fairly exhaustive bibliography on the subject, consisting of over 300 references, which we propose to circulate with the Technical Communication, but at the same time it would be helpful if those who receive this memorandum would refer us to any matter published subsequent to June, 1933, to any work in progress as yet unpublished, or to any particular publication which in the light of our thesis they think requires special mention.

¹ Marchal, P., 1928. Etude biologique et morphologique du puceron lanigère du pommier, *Eriosoma lanigerum* Hausm. *Ann. Epiphyties*, 14 : 1 : 1-106.

² Mordvilko, A. K., 1924. The Woolly Aphis (*E. lanigerum*) and other Eriosomea. Section of *Appl. Ent. of Institute of Experimental Agronomy, Leningrad*, 12 : 3 : 1-109.

³ de Fluiter, H. J., 1931. De bloedluis, *Eriosoma lanigerum* (Hausm.) *Tijdschrift over Plantenziekten*, 37 : 11 and 12 : 201-329.

QUESTIONNAIRE ON THE INCIDENCE AND CONTROL OF WOOLLY APHIS.

1. Importance of Pest.

How serious is the pest in your district? What damage does it do directly or indirectly? Is it of economic importance (a) to the grower, (b) to the nurseryman? Does the root form of the aphid do sufficient damage to be of economic importance? Can the root form of the aphid exist entirely below the surface without ever emerging?

2. Identity.

Do you consider your species to be *Eriosoma lanigerum* Hausm.? Are there more than one biologic forms, to each of which a stock may show varying degrees of resistance? Do you consider that it would serve a useful purpose for some one entomologist to collect and systematize these forms?

3. Field Control.

What control measures are ordinarily used in the field against the pest and with what success?

4. Biologic Control.

How far is biologic control efficacious?

- (a) Does *A. mali* wipe out the pest on the above-ground portions of the tree?
- (b) Does *A. mali* persist from year to year and persist in its habit of preying solely on woolly aphid?
- (c) If control is fully effective, is there any longer any need to search for immune varieties and rootstocks, or is there any objection to non-immune roots?

5. Immunity.

What do you mean exactly by the term "immunity" in connexion with woolly aphid "immune" stocks or varieties? e.g. at East Malling a Northern Spy stock is always used as control and is termed "immune." The aphid will actually feed on this for a short period in some seasons, but it has never been observed to breed on it. How is this immunity tested in your country? By observations in the field, or by direct inoculation trials or by other methods?

6. Breeding for Immunity.

Are you breeding immune stocks or varieties? If so, what parents are being used? In what quantities are these stocks available and what tests have they undergone, or are they undergoing (a) for immunity, (b) as stocks? Does this immunity hold good only under your conditions or has it been tested under other conditions, and possibly (see 2) against different biologic forms of woolly aphid? Do you think breeding experiments are worth continuing? Do you think they can best be conducted in a single country and if so, where? Do you favour evolution of immune varieties or importation of immune stocks from other countries?

7. General Principles Determining Immunity.

Do you know of any work done on methods other than direct inoculations with woolly aphid?

8. Methods of Research.

What lines of research are being adopted and where? Are researches into the fundamental causes of immunity being undertaken in your country? What form of useful collaboration can you suggest between workers in different lands to further the development or sharing out of the programme? Do you favour an agreed common technique for parallel experiments at different places?

LIST OF PERSONS REPLYING TO QUESTIONNAIRE.

ALDEN, C. H.	.. .. .	12/ 1/34	CORNELIA, GEORGIA.
/ AYYAR, T. V. RAMAKRISHNA	.. .. .	15/ 1/34	COIMBATORE, SOUTH INDIA.
BAIRD, A. B.	.. .. .	16/ 1/34	BELLEVILLE, ONTARIO.
BA TE, A.	.. .. .	16/ 5/34	MANDALAY, BURMA.
BÖRNER, C.	.. .. .	18/ 5/34	NAUMBURG/SAALE, GERMANY.
CAESAR, L.	.. .. .	13/12/33	GUELPH, ONTARIO.
CHILDS, L.	.. .. .	17/ 1/34	HOOD RIVER, OREGON.
/ CHORLEY, J. K.	.. .. .	22/ 1/34	SALISBURY, S. RHODESIA.
CUNLIFFE, M.	.. .. .	8/11/33	OXFORD.
/ CUNNINGHAM, C. C.	.. .. .	11/ 4/34	ELGIN, C. P., S. AFRICA.
CUNNINGHAM, G. H.	.. .. .	13/ 2/34	PALMERSTON NORTH, N. ZEALAND.
CUTRIGHT, C. R.	.. .. .	—	WOOSTER, OHIO.
DAVIES, W. MALDWYN	.. .. .	15/11/33	BANGOR.
DAVIS, M. B.	.. .. .	30/11/33	OTTAWA.
DORSEY, M. J.	.. .. .	21/ 2/34	URBANA, ILLINOIS.
DOTI, F.	.. .. .	18/12/33	LUGO, ITALY.
DRAIN, B. D.	.. .. .	6/ 1/34	KNOXVILLE, TENNESSEE.
ESSIG, E. O.	.. .. .	18/ 1/34	BERKELEY, CALIFORNIA.
/ FAES, H.	.. .. .	18/ 1/34	LAUSANNE.
FLINT, W. P.		21/ 2/34	URBANA, ILLINOIS.
GARDNER, F. E. and YERKES, G. E.		21/11/33	WASHINGTON, D.C.
GIBSON, A.		8/ 2/34	OTTAWA.

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DOWNES, W.			VICTORIA, BRITISH COLUMBIA.
KELSALL, A.			ANNAPOLIS ROYAL, NOVA SCOTIA.
PETCH, C. E.			HEMINGFORD, QUEBEC.
ROSS, W. A.			VINELAND, ONTARIO.
GOODWIN, W. T.		17/ 5/34	WELLINGTON, NEW ZEALAND.

Including replies from :—

ADAMSON, N. J.	.. .. .	.. .. .	HASTINGS.
GOODWIN, B. G.	.. .. .	.. .. .	CANTERBURY.
McINDOE, G. H.	.. .. .	.. .. .	OTAGO.
PAYNTER, L.	.. .. .	.. .. .	AUCKLAND.
THORP, J. H.	.. .. .	.. .. .	NELSON.
GRAY, R. A. HARPER	.. .. .	28/ 8/34	NEWCASTLE-ON-TYNE.
GRIFFITHS, H. M.	.. .. .	4/12/33	WESTMINSTER, O.F.S., SOUTH AFRICA.
GUPTA, S. R.	.. .. .	26/ 5/34	JORHAT, ASSAM.
GURNEY, W. B.	.. .. .	11/ 7/34	SYDNEY, NEW SOUTH WALES.
✓ HALL, E. G.	.. .. .	9/ 6/34	BRIDGETOWN, WEST AUSTRALIA.
HARLEY, C. P.	.. .. .	19/ 1/34	WENATCHEE, WASHINGTON.
HARMAN, S. W.	.. .. .	23/ 1/34	GENEVA, NEW YORK.
HILLIER, E. L.	.. .. .	14/ 2/34	WINCHESTER.
✓ HODSON, W. E. H.	.. .. .	15/11/33	READING.
JACK, H. W.		8/12/33	KUALA LUMPUR, F.M.S.
JARY, S. G.		16/11/33	WYE, KENT.

JENKINS, J. R. W.	22/11/33	ABERYSTWYTH.
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POTTER, G. F.	16/ 1/34	DURHAM, NEW HAMPSHIRE.
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SILVESTRI, F.	23/12/33	PORTICI, ITALY.
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THOMAS, P.	8/ 3/34	HOBART, TASMANIA.
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